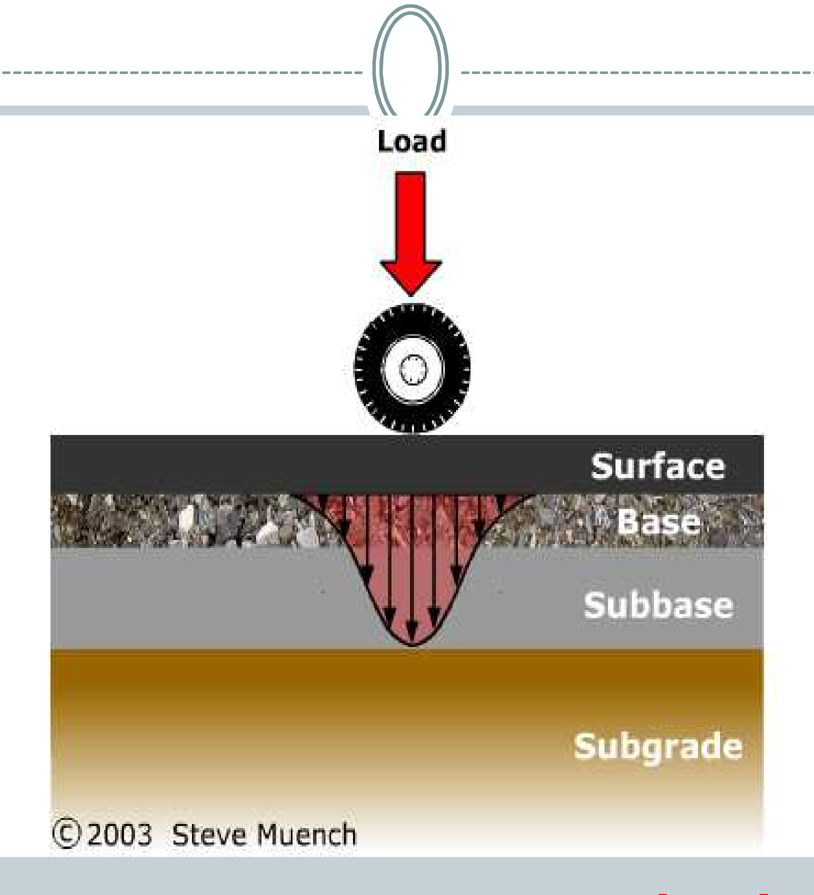
Pavement Response Under Load

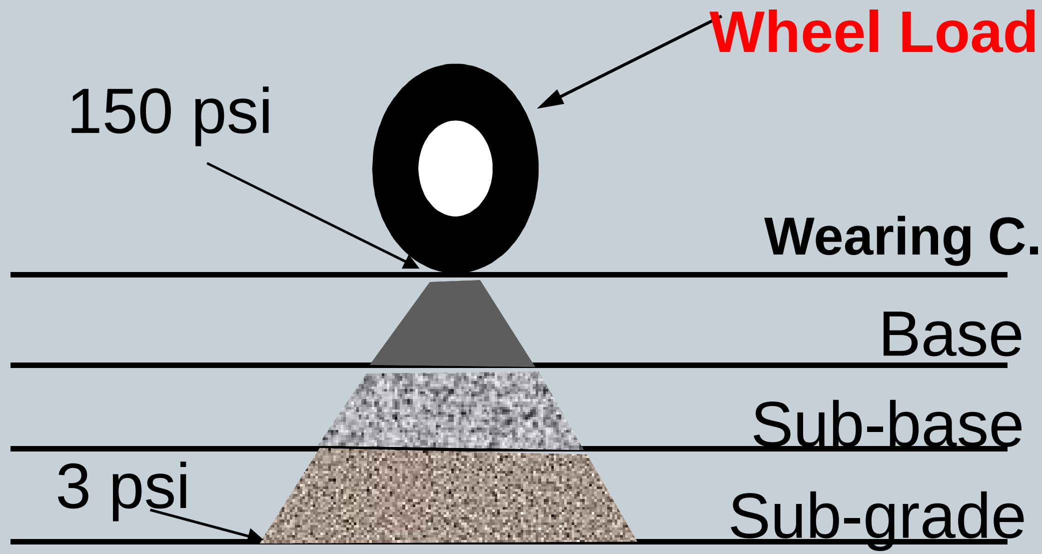
DR. ASHRAF EL_SHAHAT

FAE_ZUN

2011

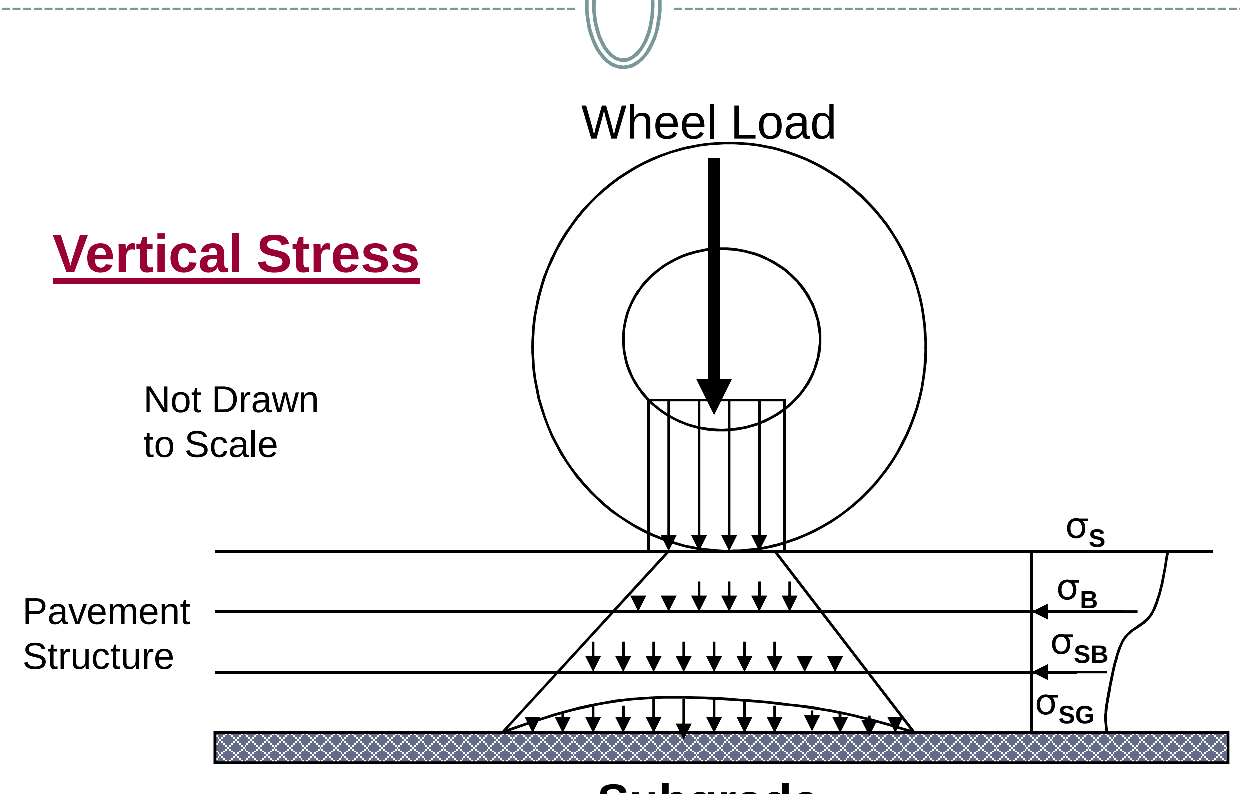
Stresses Distribution



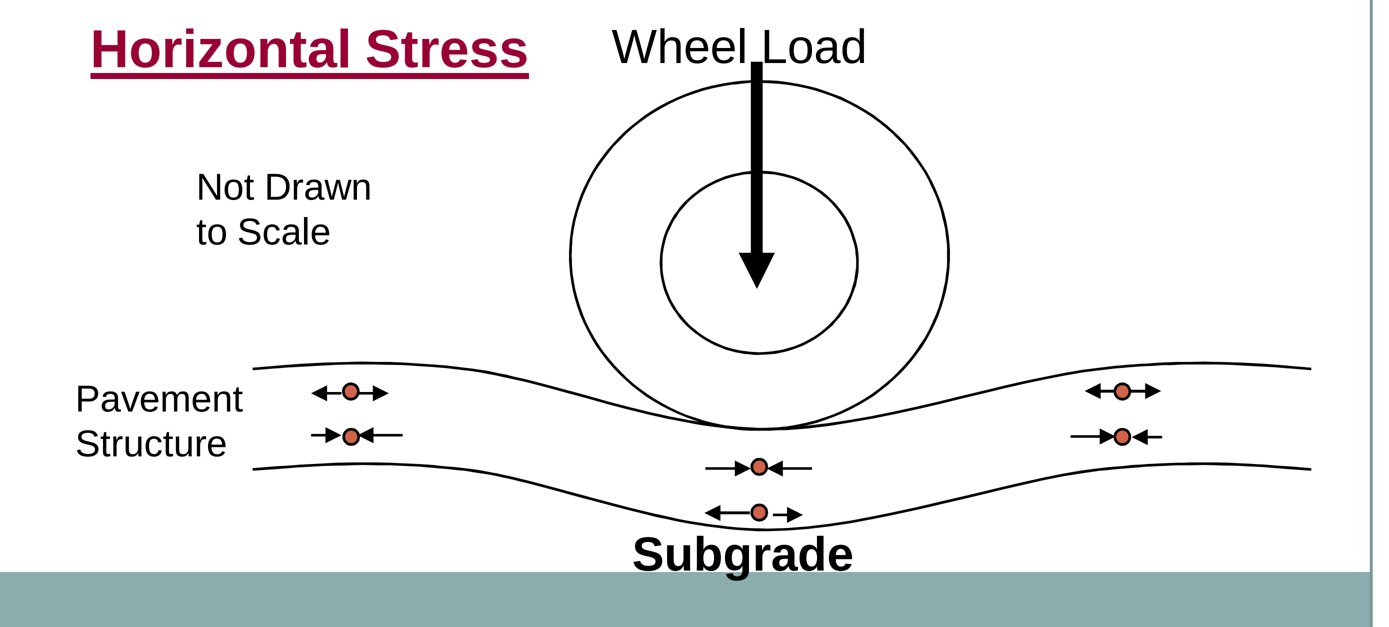


Load Distribution in Pavements

Stresses Distribution

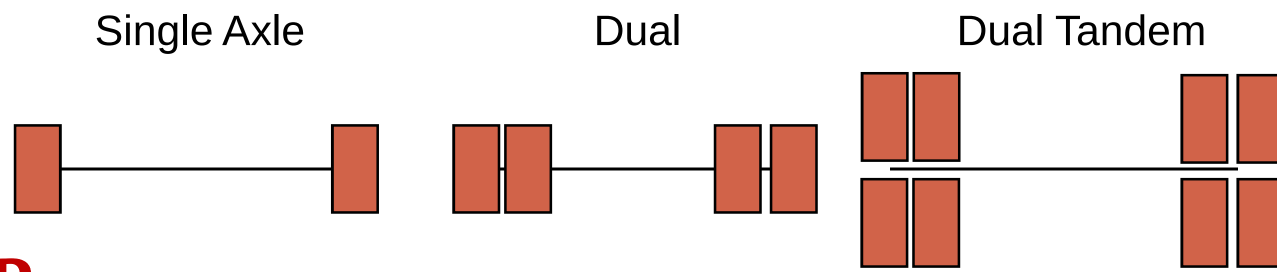




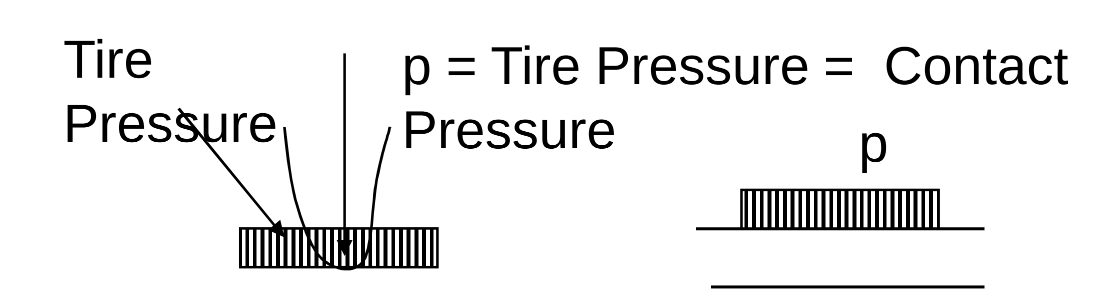


Loads and Contact Area

Load

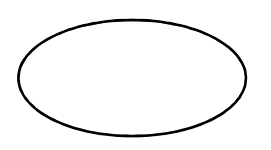
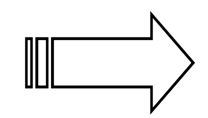
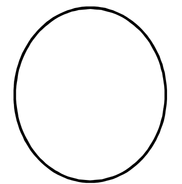
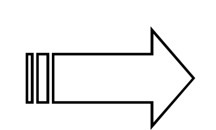
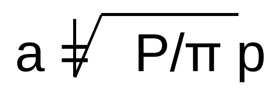


Pressure



Contact Area

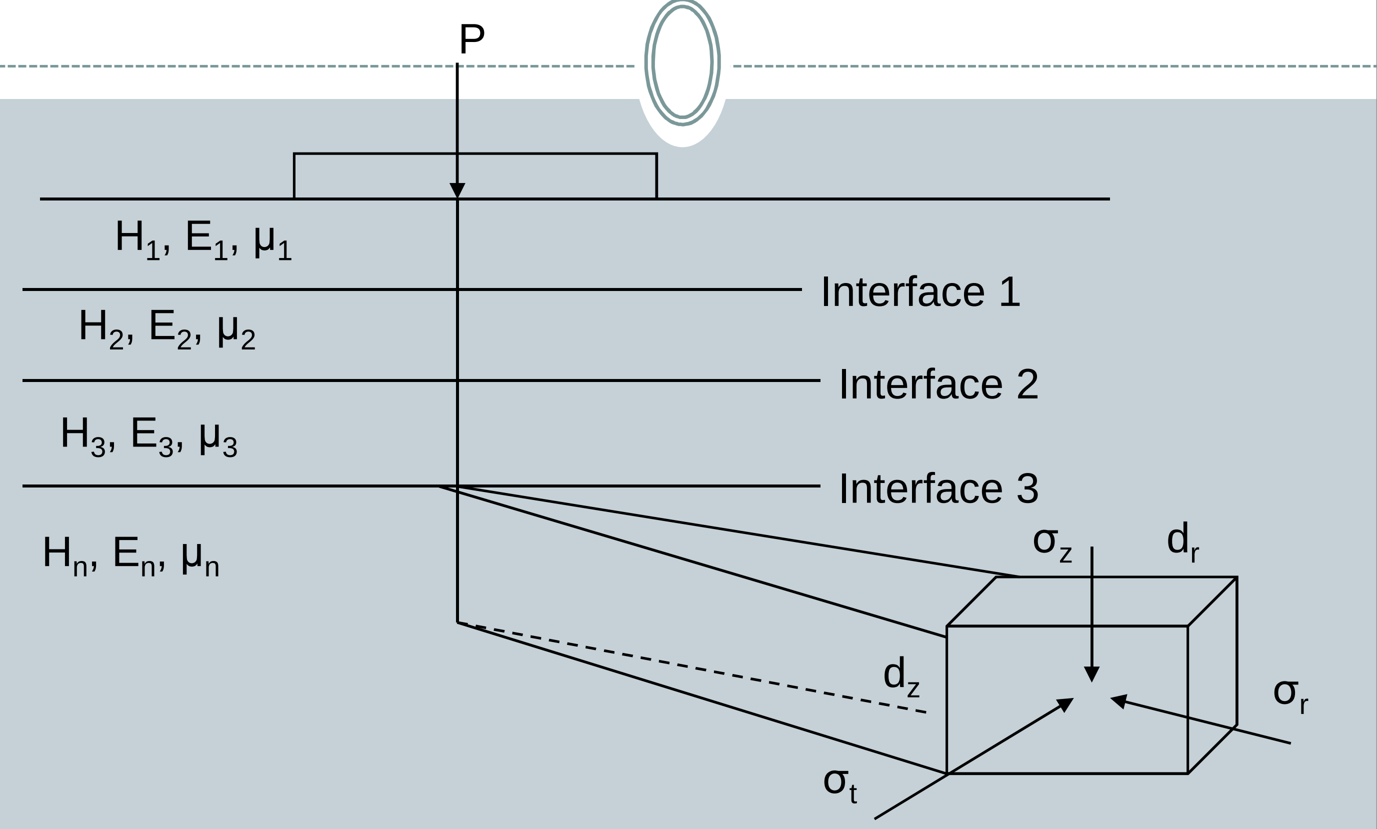
is circle with radius = a

$a = \sqrt{P/\pi p}$

- Type of Load (Static, and Dynamic)
- Tangential Forces (Acceleration, and Braking)

Multi-Layer Elastic Theory

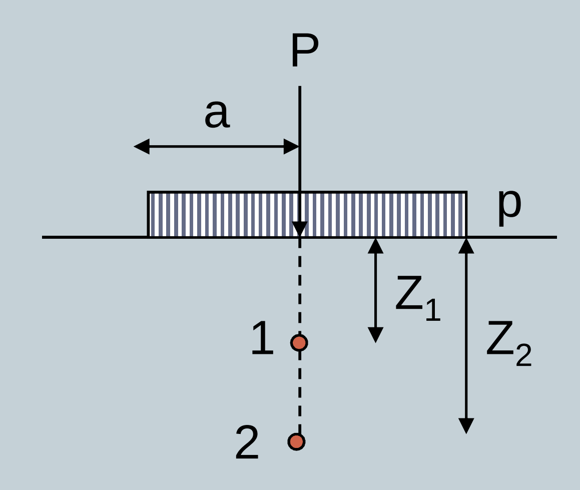


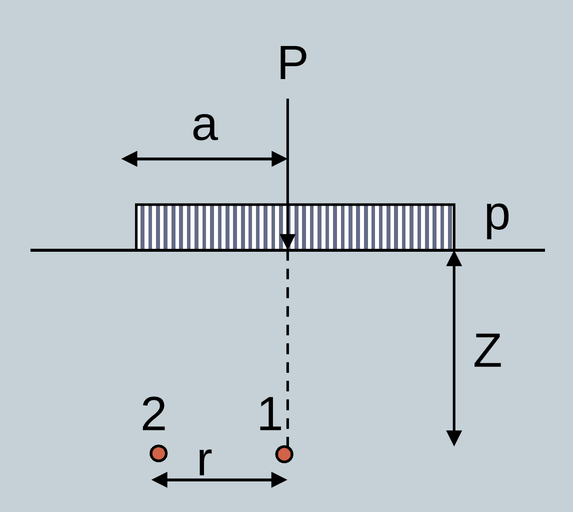
The stresses, strains, and deflection are the pavement response to the applied load. Stress is a force load per unit area, and strain is the change in dimension. Pavement stresses, strains, and deflection are caused by traffic loading, daily or seasonal temperature and moisture variations and by any change in the conditions of pavement support. The theory used to calculate stress, strains, and deflections in pavement system is the multi-layer theory.

Load Representation

Single Load

Location is defined by z & r





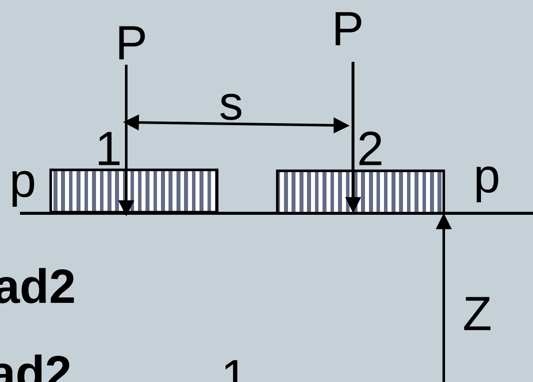
V. Stress $\boldsymbol{\sigma_1 > \sigma_2}$

V. deflection $\boldsymbol{\Delta_1 > \Delta_2}$

V. Stress $\boldsymbol{\sigma_1 > \sigma_2}$

V. deflection $\boldsymbol{\Delta_1 > \Delta_2}$

Dual Load



σ_1 =σ due to load1+σ due to load2

Δ_1 =Δ due to load1+Δ due to load2

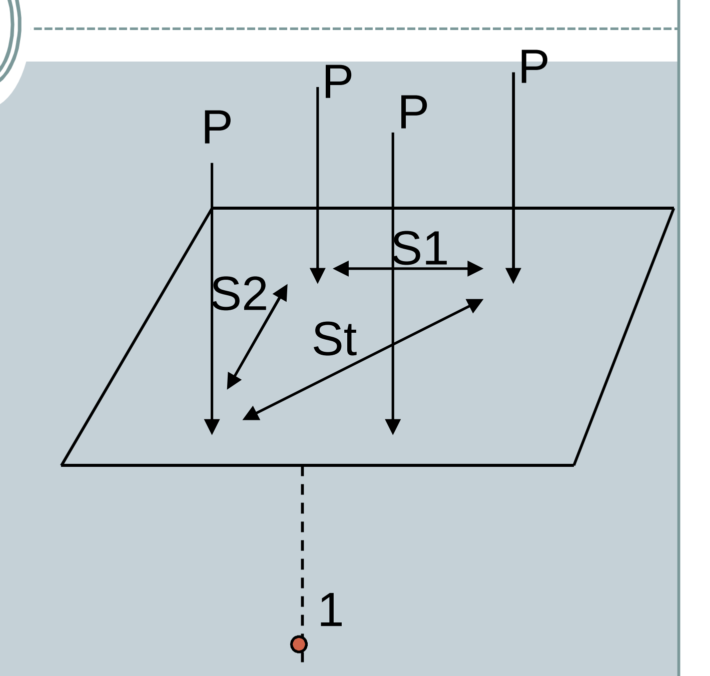
Load Representation

Dual Tandem

defined by z/a and r/a

$\sigma_1 = \sum \sigma$ due to loadi

$\Delta_1 = \sum \Delta$ due to loadi



How to Calculate Stress & Deflection

One Layer Theory → Stress / Deflection

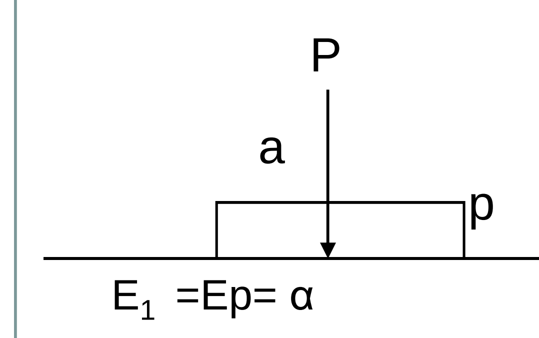
For any system of loads

Two Layers Theory → Stress / Deflection

Under single load

One Layer Theory

(Boussinsq Theory)



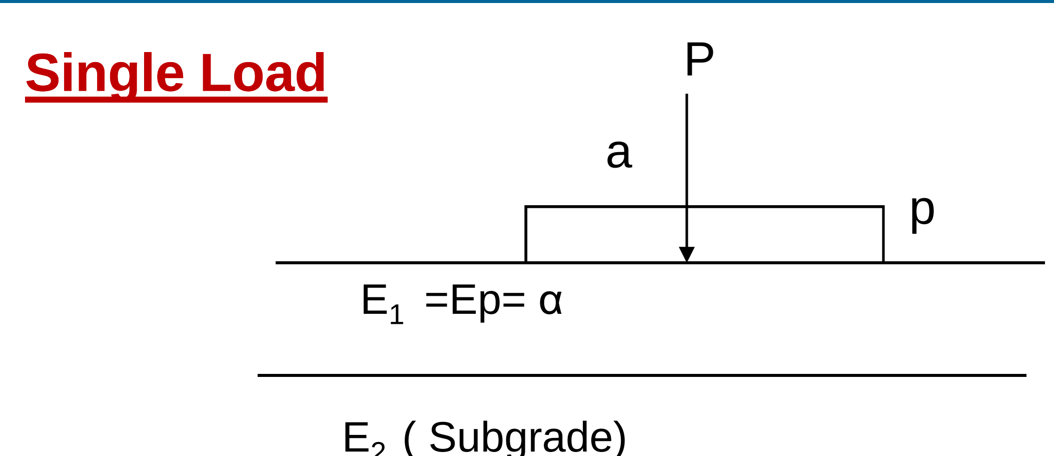
No deflection in the pavement structure …..all deflection is in the subgrade

So, the layered system is composed of only ONE LAYER (Subgrade)

This layer follows the same assumption of the Elastic Multilayer Theory

Vertical Stress (σ) & Vertical Deflection (Δ)

Single Load

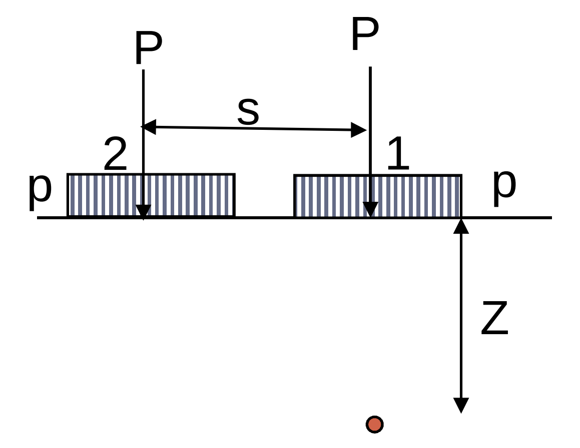


1) Using (z/a, r/a) ⟶ Figure (1) ⟶ $m = \sigma/p$ ⟶ σ

2) Using (z/a, r/a) ⟶ Figure (2) ⟶ F ⟶ $\Delta = pa*F/E_2$

One Layer Theory

(Boussinsq Theory)



Dual Load

$$\boldsymbol{\sigma}_{\text{total}} = \boldsymbol{\sigma}_1 + \boldsymbol{\sigma}_2$$

σ_1 (z/a, r/a)…….$m_1 = \sigma_1 / p$

σ_2 (z/a, r/a)…….$m_2 = \sigma_2 / p$

$$\boldsymbol{\Delta}_{\text{total}} = \boldsymbol{\Delta}_1 + \boldsymbol{\Delta}_2$$

Δ_1 (z/a, r/a)……F_1…. $\Delta_1 = paF_1/E_{subgrade}$

Δ_2 (z/a, r/a)……F_2…. $\Delta_2 = paF_2/E_{subgrade}$

Same procedure for **Tandem Load** ………… 4 times

One Layer Theory

(Boussinsq Theory)

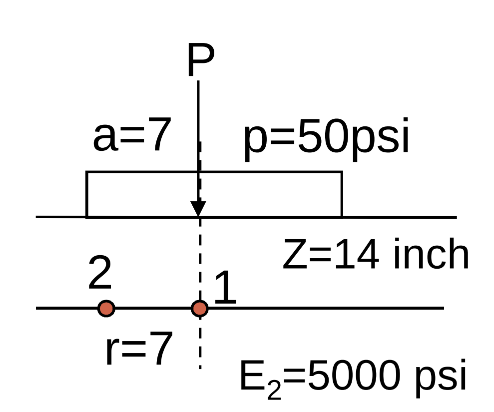
Example

$z_1/a = 2$, $r_1/a = 0$ ……….$m_1 = 30\%$

$m_1 = \sigma_1 / p$ ……. $\sigma_1 = 0.3*50 = 15$ psi

$z_2/a = 2$, $r_2/a = 1.0$ ………$m_2 = 20\%$

$m_2 = \sigma_2 / p$ ……. $\sigma_2 = 0.2*50 = 10$ psi



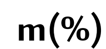
$z_1/a = 2$, $r_1/a = 0$ ……….$f_1 = 0.7$

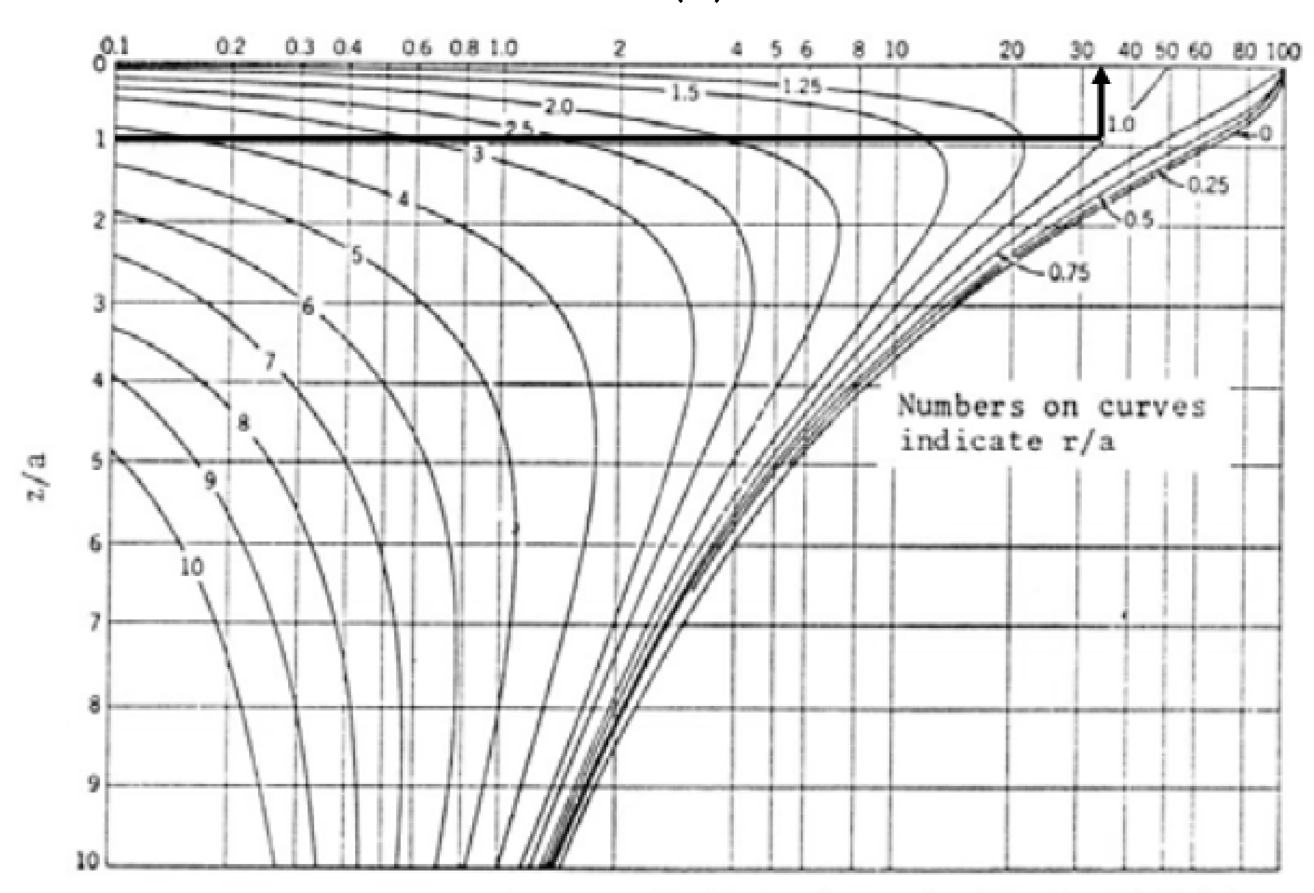
$\Delta_1 = paF_1/E_{sub} = 50*7*0.7/5000 = 0.049$

$z_2/a = 2$, $r_2/a = 1$ ……….$f_2 = 0.57$

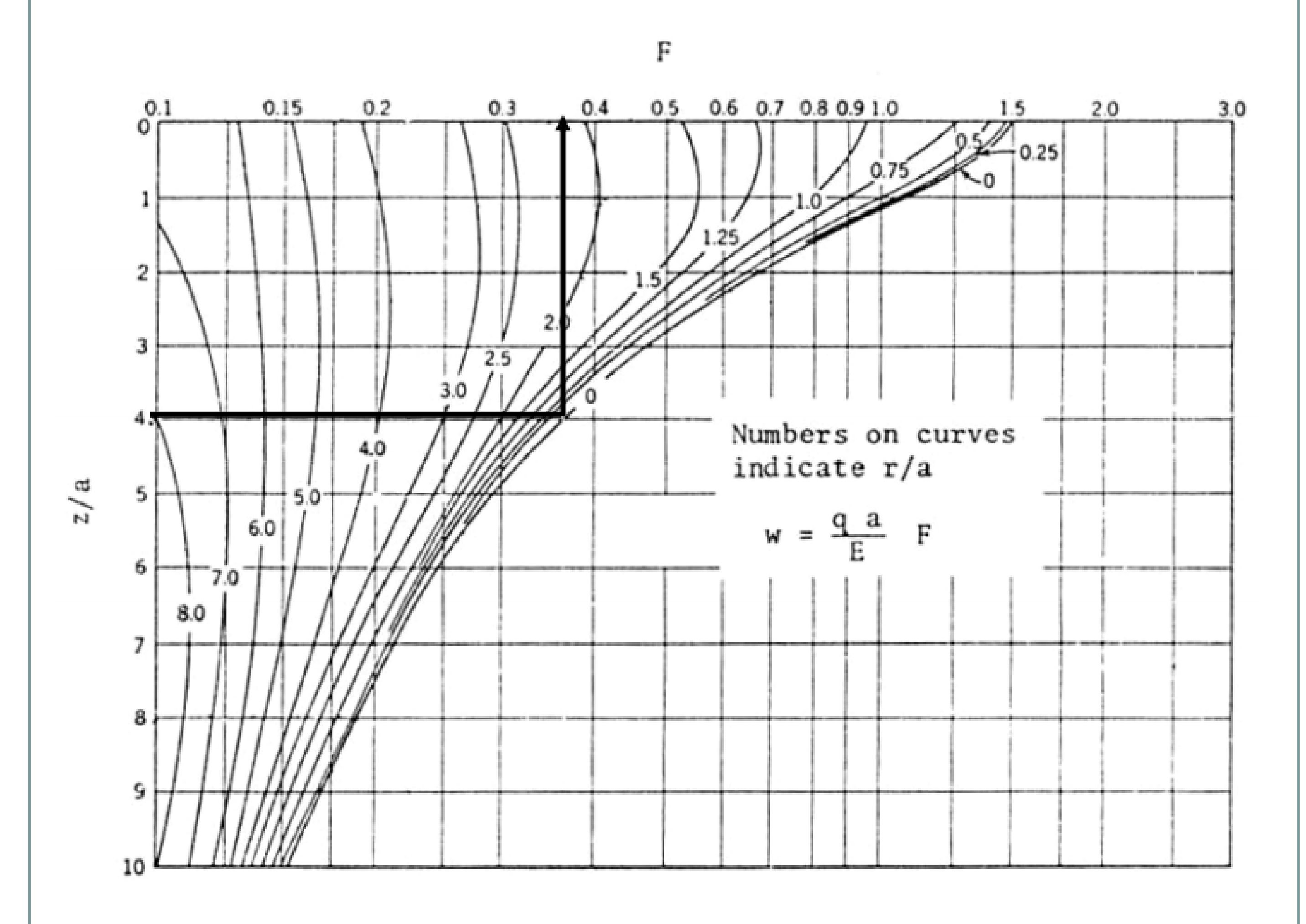
$\Delta_2 = paF_2/E_{sub} = 50*7*0.57/5000 = 0.04$

Vertical Stress (σ)





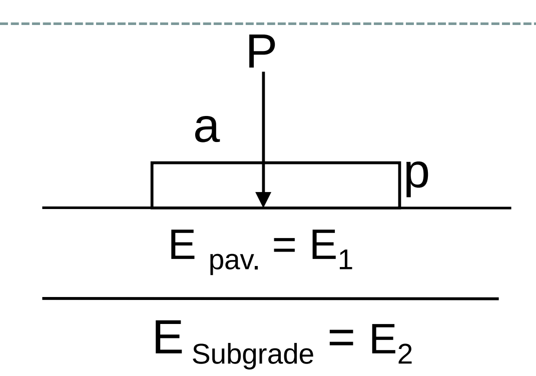
Vertical Deflection (Δ)



Two Layer Theory

(Burmister Theory)

1- Same assumption as in the Multilayer theory



2- In this theory, pavement deflection is considered

3- Deflection at depth Z in a two layer system given by:

$\Delta = 1.18 \; paf/E_{sub}$ (Rigid Pav.)

$\Delta = 1.5 \; paf/E_{sub}$ (Flexible Pav.)

Δ = vertical deflection under CL of the applied load

p = tire pressure (psi)

$a = \sqrt{P/\pi p}$

E_{sub} = Subgrade modulus of elasticity

f = two layer deflection factor

Two Layer Theory

(Burmister Theory)

4- This theory is applied only to one load and r/a = 0

5- When Z/a = 0 F = 1.0 for any E_2 / E_1 ratio

6- If it is required to calculate deflection in two layers system under dual or dual tandem load system, the thickness conversion method described earlier can be used to convert the two layers to one layer system.

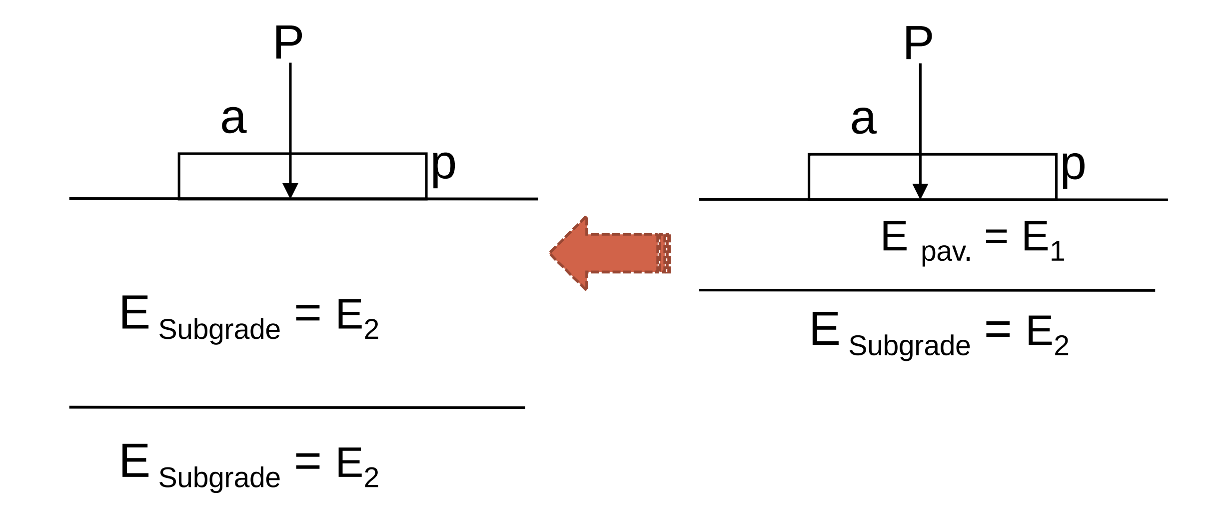
Two Layer Theory

(Burmister Theory)

Layer Equivalency

It is the conversion of a thickness of a layer of material with known modulus to an equivalent thickness of another material with known modulus using the formula

$$Z_{sub.} = Z_{pav.} \sqrt[3]{E_1/E_2}$$

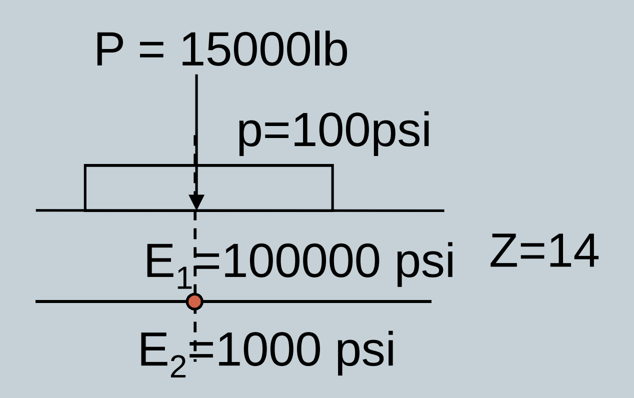


Two Layer Theory

(Burmister Theory)

Example

$a = \sqrt{15000 / \pi*100} = 7.0$



Two layer

z/a = 2 , E2 / E1 = 1/100 ….f’ = 0.13

Δ = K paf /E_{sub}= 1.5 *100*7*0.13/1000= **0.137**

One layer

z/a = 2 , r/a = 0 ……….f1 = 0.69

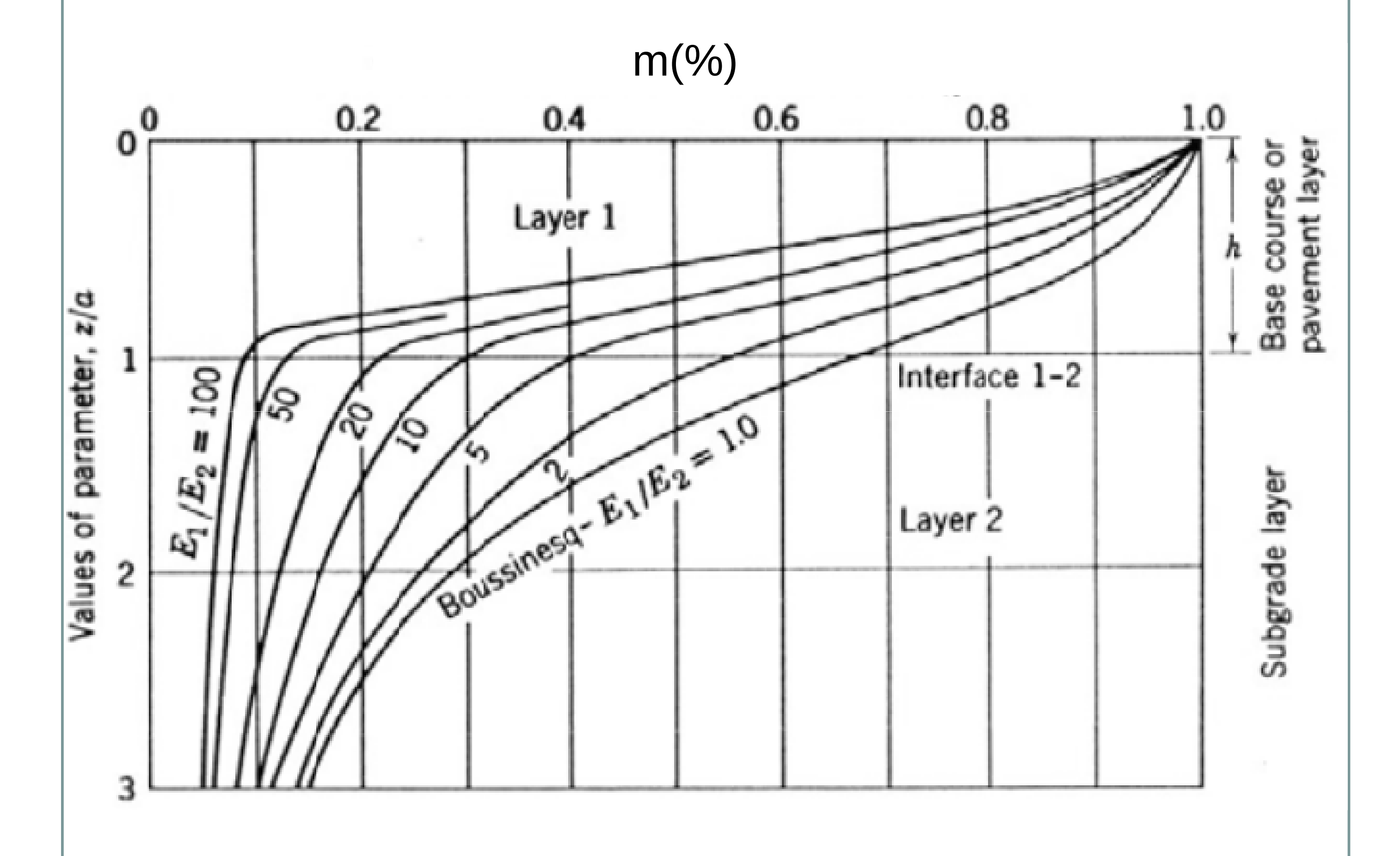
Δ = paF_1/E_{sub} = 100*7*0.69/1000 =**0. 483**

Conversion

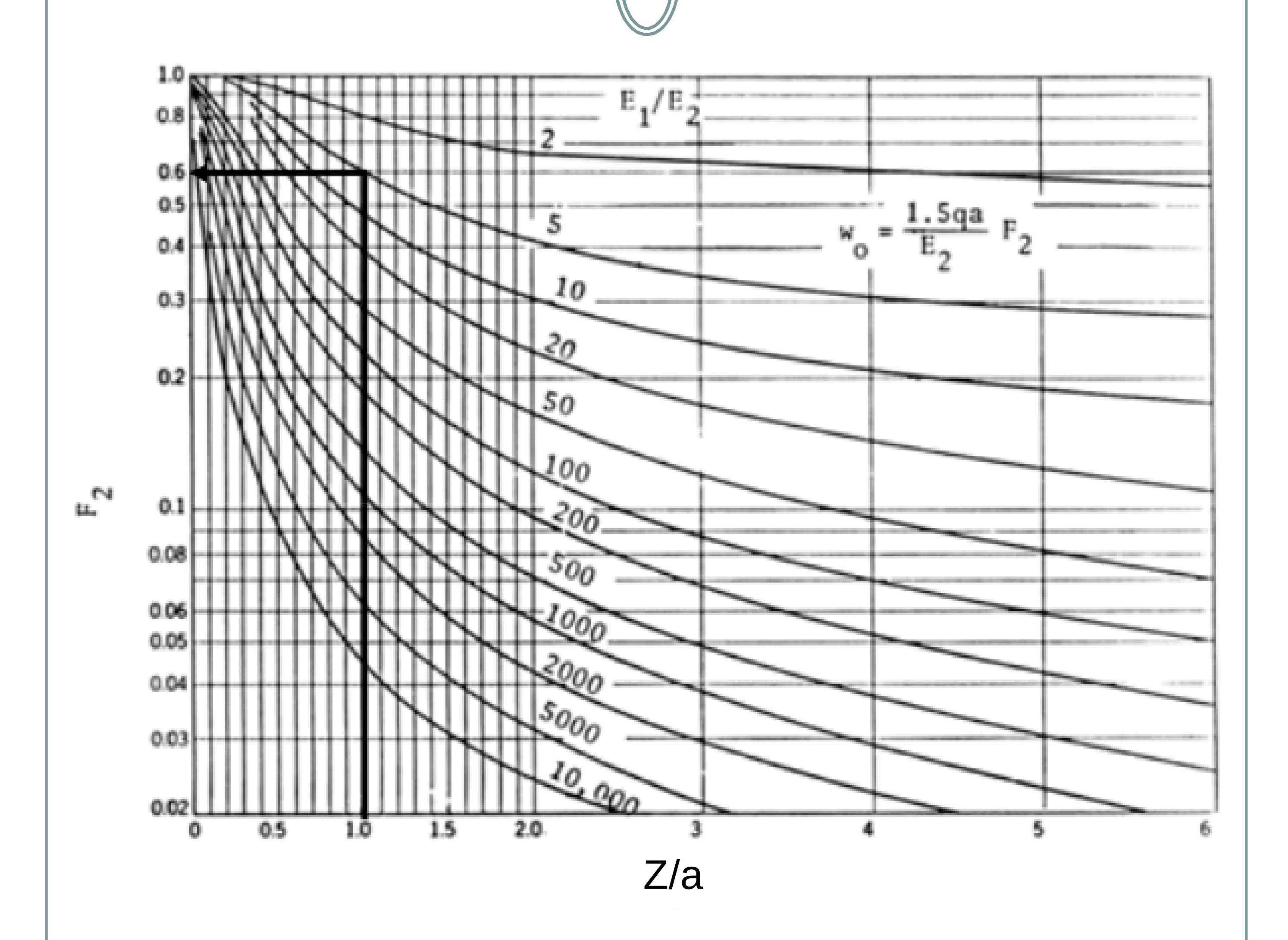
Z = Z pav. $\sqrt[3]{E1/E2}$ = 14 $\sqrt[3]{100000/1000}$ =65

Δ = paF1/Esub = 100*7*0.17/1000 =**0. 12**

Vertical Stress (σ)



Vertical Deflection (Δ)



Pavement Evaluation

Use of Multilayer theory in pavement evaluation

- Pavement evalaution ....to find E_1 & E_2

- Since the two layer theory (or multilayer thoery, in general) links between the pavement deflection and its characteristics, i.e. E_1 & E_2, then if we can measure the deflection, it will be easy to back calculate E_1 & $E_{2.}$

- Plate Bearing Test is used to measure the deflection of subgrade under given load.

P

a = 15

Rigid plate

How to get E1 & E2 Using the Plate Bearing Test

1- Put the Plate on the top of subgrade and measure the deflection (Δ) at the top of subgrade (i.e. z = 0.0)

P

a = 15

Rigid plate

Subgrade

$p = P / \pi (15)^2$

using the two layer theory

$\Delta = K\, p\, a\, F' / E_2$

Δ is measured, K = 1.18, F' = 1.0 (for z/a = 0.0), and p & a is known

.........then get E_2

How to get E1 & E2 Using the Plate Bearing Test

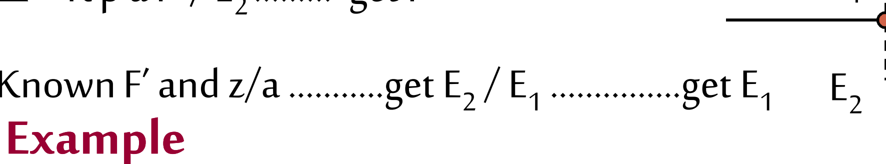
2- Put the Plate on the top of the base (or pavement materials) and measure the deflection (Δ) at the top of subgrade using the two layer theory

P

Z=choused

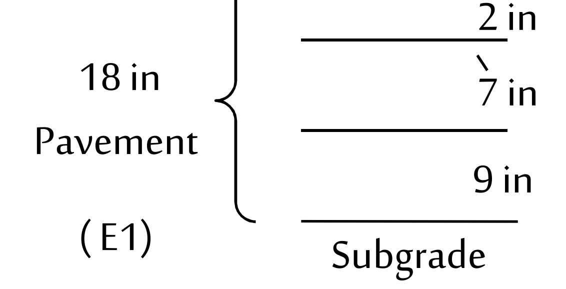
$\Delta = K\, p\, a\, F' / E_2$ .... get F'

Known F' and z/a ....get E_2 / E_1 ....get E_1



Example

A certain flexible pavement consists of 2-in bituminous surface, 7-in crushed stone base course, and 9-in sandy subbase. A 30-in rigid plate was used to determine the load- deflection characteristics. The following results were obtained

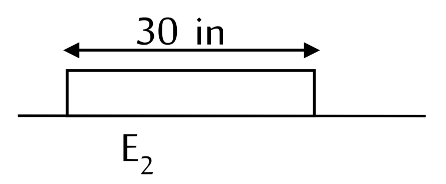


1- subgrade deflection = 0.10 in at 20 psi

2- Pavement deflection = 0.10 in at 98 psi

Solution:

step (1)



$\Delta = 0.1 = K\, p\, a\, F' / E2$

$0.1 = 1.18 \times 20 \times 15 \times 1 / E2$

E2 = 3540 psi

Pavement Evaluation

step (2)

E_1

Z=18

E_2=3540 psi

$\Delta = 0.1 = K\ p\ a\ F' / E2$

$0.1 = 1.18 \times 98 \times 15 \times F' / 3540$

$F' = 0.204$ (using Chart with $z / a = 18/15 = 1.2$ and $f' = 0.204$)

$E2 / E1 = 1 / 80$ …… $E1 = 80 \times 3540 = 283200$ psi

Given	Req.	SWL	Multiwheel load
P , Z	σ	Chart	Chart
P, Z	Δ	Chart, Equation	Chart, Equation
P, σ max.	Z	Chart	Drawn Relation (σ , Z)
P, Δ max.	Z	Chart, Equation	Drawn Relation (Δ , Z)
Z , σ max.	P	Chart	Drawn Relation (σ , P)
Z, Δ max	P	Drawn Relation (Δ , P)	Drawn Relation (Δ , P)

Given : Z, p, Δ max., E2

Req. : P

1- Assume P $a = \sqrt{P / \pi p}$

2- Calculate Δ

3- If $\Delta = \Delta$ max. ……..P req. = P

4- if not repeat 3 to 4 times to draw the shown relation and find Preq at Given Δ

الحمد لله

